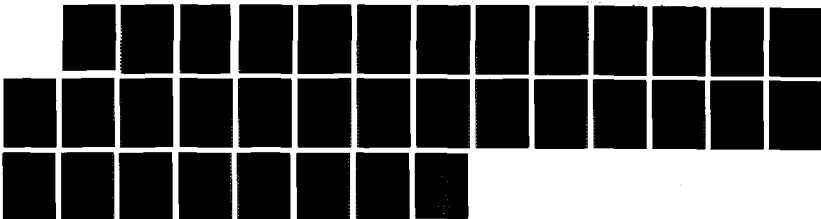


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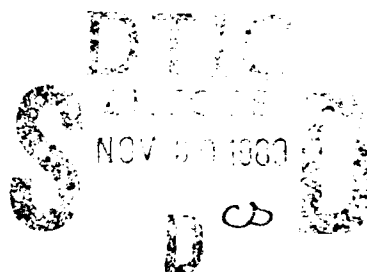
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DELTA 181 SENSOR MODULE COMMAND CENTER

R. J. HEINS

A. A. CHACOS

M. J. HERMES



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1. OVERVIEW

1.1 SUMMARY

In February 1988 an APL-designed sensor module was launched into orbit by a Delta rocket to perform a number of strategic defense initiative (SDI) program experiments. The principal objective was the formation of a useful database for future SDI planning. After launch, sensor module command, control, and monitor operations were performed from a facility called the sensor module command center. The command center, installed at Cape Canaveral Air Force Station, Fla., was designed and operated by APL. This paper presents an overview of the command center design and mission configuration.

The command center installation consisted of an operations room and an equipment room. The operations room was staffed by the sensor module mission operations team and contained the control terminals, data displays, and voice communication gear to conduct sensor module command and monitor operations. The equipment room, located on a separate floor in the same building, housed command center computer and interface hardware.

Post-launch mission operations involved a network of worldwide facilities called the control complex. The command center was an integral component of the control complex and interfaced to it as shown in Fig. 1-1. It should be noted that Fig. 1-1 shows only those control complex assets that were involved with command center interface or operations. The entire control complex was far more complicated.^{2,3}

As shown in Fig. 1-1, real-time commands sent from the command center and telemetry data returned to the command center were communicated through control complex assets. From a mission perspective, operation of the command center was tightly coupled to control complex operation. Therefore, before we proceed with a detailed description of command center design, details relating to the control complex and the mission are given below, to place the command center design in overall context. For additional background, an overview of sensor module command and telemetry links is presented in appendix A.

1.2 MISSION DESCRIPTION

1.2.1 Experiment Data Collection

The sensor module was boosted into a 23°-inclination orbit by Delta 181, launched from Cape Canaveral. The on-orbit spacecraft assembly included (in addition to the sensor module) the Delta second stage (Delta 2), which provided attitude control and orbit adjustment during the mission. The sensor module payload included a canister that housed reference and experimental test objects. After orbit insertion, the test objects were deployed in a controlled sequence. Instruments on board the sensor module (passive infrared and ultraviolet sensors, laser radars, and a microwave radar) observed and tracked the test objects over a range of environmental background conditions.

During the first ten orbits, all experiments were conducted and sensor module instrument science data was stored on on-board recorders. Also preparations were made for downlinking recorded data. During this phase of the mission (called the data-collection phase) the command center was very active in supporting real-time command operations and monitoring sensor module performance.

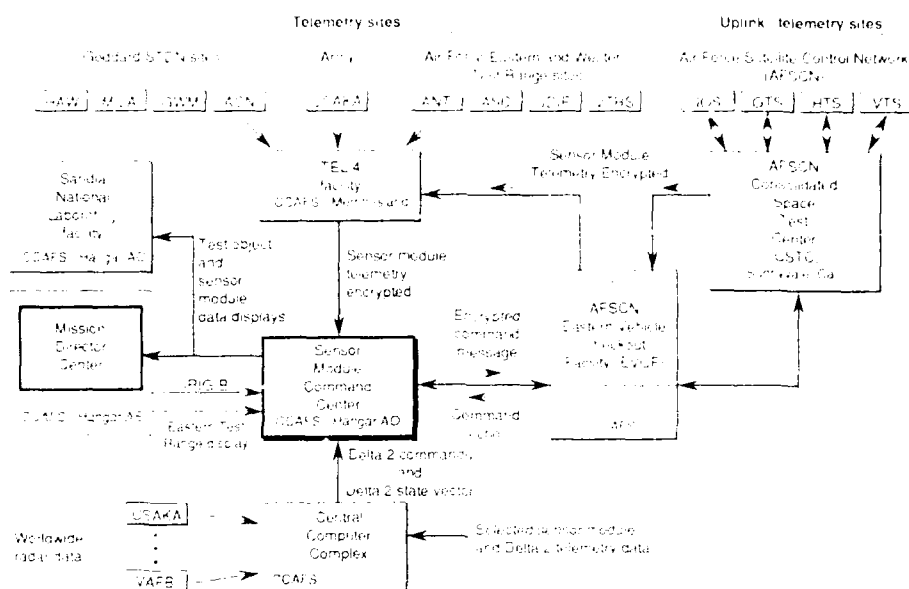


Fig. 1-1 Sensor module command center interface.

1.2.2 Data Retrieval

At the end of the data-collection phase, in accordance with the mission plan, the command center loaded the sensor module with instructions to begin what was called the data-retrieval phase. During that phase, the sensor instruments were off; the task of the control complex was to retrieve the instrument science data previously stored on board the sensor module. The data-retrieval phase consisted of ground operations to control playback of stored sensor-module instrument data and record those data at ground tracking sites.

As called for by the mission plan, sensor module command and control operations were shifted to the Air Force Consolidated Space Test Center in Sunnyvale, Cal., for the data-retrieval phase. During this phase, the command center at Cape Canaveral was on standby for contingency command operations, and operators continued to monitor and evaluate sensor module health. This period, approximately one week in duration, ended when two complete dumps of sensor module instrument science data were recorded at control complex spacecraft tracking sites.

1.3 POST-LAUNCH OPERATIONS CONTROL COMPLEX

1.3.1 Command and Telemetry Sites

The control complex consisted of a combination of worldwide assets of the Eastern Test Range, the Kennedy Space Center, the U.S. Air Force, and the U.S. Army. Four spacecraft tracking sites were used for command uplink and 13 sites were used to recover telemetry. The sites, all reasonably close to the equator, provided optimum ground coverage for support of command uplink and telemetry downlink operations. The four command uplink sites, located at Guam (GTS), Hawaii (HWS), Vandenberg (VTS), and the Indian Ocean (IOS), are part of the Air Force Satellite Control Network (AFSCN).

1.3.2 Narrowband and Wideband Data Links

Sensor module narrowband and wideband data links are described in Appendix A. The narrowband data link carried data required by the command center to verify commands and to monitor sensor module configuration and health. When the sensor module was in view of a tracking site, narrowband telemetry was received and relayed to the command center in real time. The TEL-4 facility, located at Cape Canaveral, collected, and distributed sensor module telemetry to the command center.

The telemetry sites also recorded select wideband science data during the data collection phase. The wideband data consisted of real-time science data from the sensor instruments. These data were recorded at ground tracking sites, when they were in view of the sensor module, and were processed following the mission. Note that wideband data were not required by the command center to perform mission operations and thus were not input to it.

1.3.3 AFSCN Network

As illustrated in Fig. 1-1, all commands sent from the command center were sent to the sensor module through the AFSCN. During supported passes, when an uplink tracking site was in view of the sensor module, the command center sent commands in real time to the Eastern Environmental Checkout Facility (an AFSCN asset), located near the command center at Cape Canaveral. From that facility, sensor module commands were sent, via the AFSCN network, to the tracking site. From the tracking site the commands were uplinked to the sensor module. The time required for a command to travel from the command center to the sensor module was less than 2 seconds.

Note that all commands sent from Cape Canaveral were routed through the AFSCN Consolidated Space Test Center (CSTC) located in Sunnyvale, Cal. The CSTC facility transmitted the commands to the tracking site that was currently in view of the sensor module. Before each supported pass, CSTC established command and telemetry links with that site. During the pass, commands sent from Cape Canaveral were then automatically routed to that site. The CSTC facility also collected narrowband telemetry from the AFSCN tracking site and sent it back to control complex facilities at Cape Canaveral.

1.3.4 Other Command Center Facilities

Up to this point, we have described how the worldwide spacecraft tracking sites, the TEL-4 facility, and the AFSCN together supported command and telemetry links to the command center. We shall now give a very brief outline of how the remaining Cape Canaveral facilities supported command center operation.

1.3.4.1 Mission Director Center. A facility called the Mission Director Center served as the mission control center for the data collection phase of the mission. Mission managers and technical advisors stationed there assessed all aspects of mission operation. Through the operations director, top-level instructions were issued to the command center and to other control complex facilities to coordinate all ground-based operations.

The Mission Director Center staff included APL technical advisors. To support those advisors, command center computers interfaced to a number of terminals located in the Mission Director Center that displayed sensor module telemetry data.

The command link from the command center to the sensor module was unique. The command center sent command not only to the sensor module, but also to the Delta 2 inertial guidance computer and test objects (see Appendix A). In this

ward, the Mission Director Center staff played a crucial role in command center uplink operations. They authorized all uplink operations and received all commands and command requirements. Through the operations director, the command center was instructed periodically on command uplink requirements.

1.3.4.2 Central Computer Complex. The sensor module RF uplink was used to send commands to the Delta 2 inertial guidance computer. In the control complex, Delta 2 commands were configured in a facility called the Central Computer Complex, that were sent from the command center. To accomplish this, the command center supported a Delta 2 command link to the Central Computer Complex. The command center received the configured commands in a digital format, reconfigured the commands into the correct uplink format, and sent them to the sensor module. During the mission a number of such commands were sent from the command center.

The nature of the Delta 2 commands (Delta 2 inertial guidance computer) required precise and timely knowledge of the actual Delta 2 inertial guidance module orbit, as measured by radar tracking. The Central Computer Complex was a natural selection as the facility to perform this task, since its normal function at Cape Canaveral is to receive and process radar tracking data. That facility is already configured to receive radar data on orbiting spacecraft from a worldwide network of radar sites. For this mission, the Central Computer Complex was upgraded to configure Delta 2 inertial guidance computer commands and support the command link to the command center.

1.3.4.3 Command Center Sandia Link. The command center also provided decrypted narrowband telemetry data and test object displays to the Sandia National Laboratory ground support facility. A team at this facility, in concert with technical advisors in the Mission Director Center, evaluated overall performance of the test objects built by the Sandia National Laboratory. At key times during the mission, decisions were required as to the necessity of sensitive test object command uplink operations. Such decisions were based partly on telemetry and displays provided by the command center.

2. SENSOR MODULE COMMAND CENTER INSTALLATION

The command center operations room and the equipment room were located in Hangar AO of Cape Canaveral Air Force Station. They were installed on separate floors, with the operations room located above the equipment room. Mission operations required staffing of both areas, and voice links were required to coordinate internal command center operation.

The block diagram of Figure 1 shows a more detailed functional breakdown of the command center. Detailed interconnection between major command center subsystems and the control complex is also shown. The equipment room housed command center uplink and downlink subsystem equipments, which included computers and all electrical interfaces to control complex facilities. The computers supported terminals and printers located in the operations room. These terminals provided the operator interface for sending uplink commands and monitoring sensor module health and status. The downlink subsystem, linked to the TFI-4 facility, processed narrowband telemetry and provided all capabilities to monitor the sensor module. The uplink subsystem, linked to the AFSCN network and the Central Computer Complex, provided the capability to perform sensor module command and control.

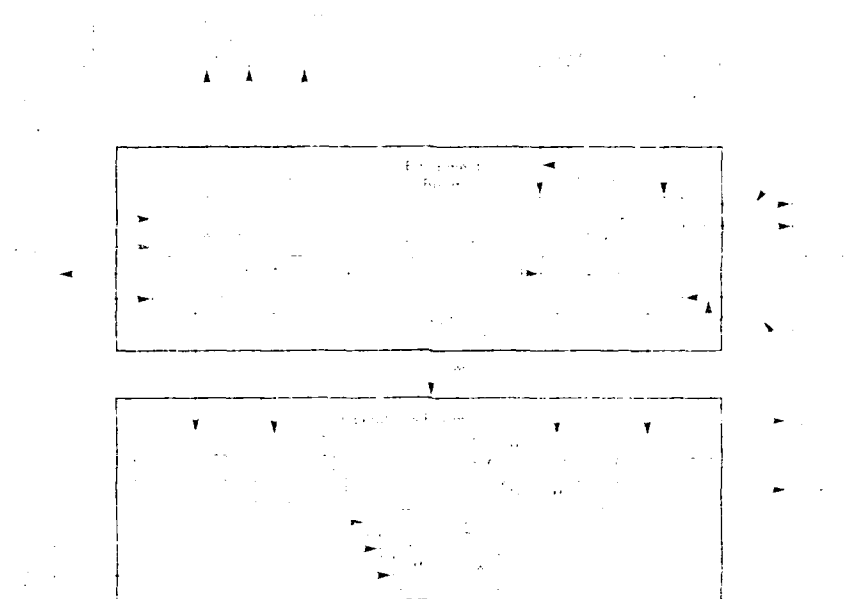


Fig. 2-1 Sensor module command center block diagram

2.1. COMMAND CENTER OPERATIONS ROOM

The operations room included, in addition to the terminals and printers driven by the command center computer, data display monitors, voice communications units, and a link station provided by the Eastern Test Range. This room, especially the voice communications equipment, was vital in that it provided the necessary links for coordinating command center operations with operation of the control centers.

2.1.1. Organization

Figure 2.2 illustrates the general layout and staffing of the command center operations room. For security reasons, no photographs of the installation were allowed. The operations room was organized around two console rows in which control and display equipments were installed. Five staff positions were implemented on each row. Each position was dedicated to a specific staff function, and was configured with the appropriate display and control equipments. Each operator position included a display console and keyboard, and a voice communications panel/headphone set. A number of the positions also included Eastern Test Range data display monitors. Forward of the console rows, Greenwich Mean Time, countdown time, and time after lift-off (TAFO) were displayed on wall-mounted units. Two Eastern Test Range data displays were projected onto wall-mounted screens.

2.1.2. Computers

The downlink computer supported four terminals and two personal computers in the operations room. These devices were positioned to support the sensor module health monitor, to facilitate the sensor module subsystem analysts (RI and RI) and the sensor module health monitor data display, and the flight processor and the flight processor data display and print functions for

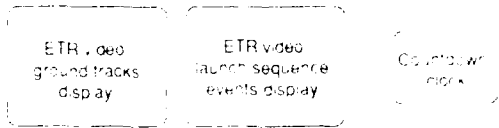


Fig. 2-2 Command center operations room

monitor of sensor module health and status. The personal computers provided specialized data analysis and graphic displays of the flight processor data component of telemetry.

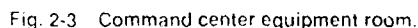
The command center computers also supported three display terminals and a personal computer located in the Mission Director Center, and a display terminal located in the Sandia National Laboratory facility. These devices provided telemetry display capabilities identical to those available within the command center.

Three terminals and a personal computer in the operations room were connected to the uplink subsystem computer. The APLCOM (APL communications language) terminal (at the uplink controller location), was the only terminal from which sensor module commands, Delta 2 guidance computer commands, or test object commands could be sent. Command verification results were also posted to this terminal. The other terminals and personal computer supported the command center director, the alerts analyst, and sensor module advisor. They were used to monitor Central Computer Complex interface status, to generate updated station alerts, and to run utility programs in support of uplink planning.

As previously noted, a number of the operations room staff positions included Eastern Test Range-generated data displays. Those displays included sensor module orbital ground tracks, selected Delta 2 telemetry, prelaunch countdown events, and live television coverage of control complex facilities (launch pad, Mission Director Center, etc.). The displays were useful to the command center staff in keeping abreast of control complex and mission operations.

2.2 COMMAND CENTER EQUIPMENT ROOM

The equipment room, which housed the uplink and downlink subsystems hardware, included the downlink and uplink MicroVax II computer systems, an uninterruptible power system, and five racks of interface and test equipment. The layout of that room and the equipment is shown in Fig. 2-3. Again, because of security considerations, no photographs of the actual facility were allowed.



The command center also included its own uninterruptible power system (UPS). This system was required because of the power line transients and outages commonly experienced at Cape Canaveral. It powered all command center equipment, including the terminals and printers located in the operations room. This system, an Immunelec series 31, had a 15 kVA capacity, and included power conditioning and a backup battery pack. The uninterruptible power system isolated input power perturbations from command center equipment and, in the event of a complete power outage, delivered uninterrupted power for a minimum of 15 minutes. In the event of long-term power outage, the Eastern Test Range maintained on a stand-by basis during the mission a backup diesel power generator. The uninterruptible power system operated using either commercial AC power or the back-up generator.

3. UPLINK SUBSYSTEM DESIGN

Figure 3-1 shows a more detailed view of the uplink hardware. For clarity, the patch panel and switches used to interconnect the various equipment are not shown. Some of the more commonly used test signal test paths are indicated by dashed lines.

The core of the uplink was the MicroVax II computer system. It included two 750 Mbyte hard disks and a tape transport unit. Uplink software resident in this computer could generate, send, and verify commands. The command formatter, encryptor, and AFSCN formatter equipments functioned to interface uplink messages output by the computer for transmittal to the sensor module. The echo processor, decryptor, AFSCN depacketizer, and bit sync equipment, processed the command echo returned from the AFSCN, and verified operation of the entire ground portion of the uplink.

Uplink command and command verification functions were implemented in both hardware and software. A description of key uplink functions follows.

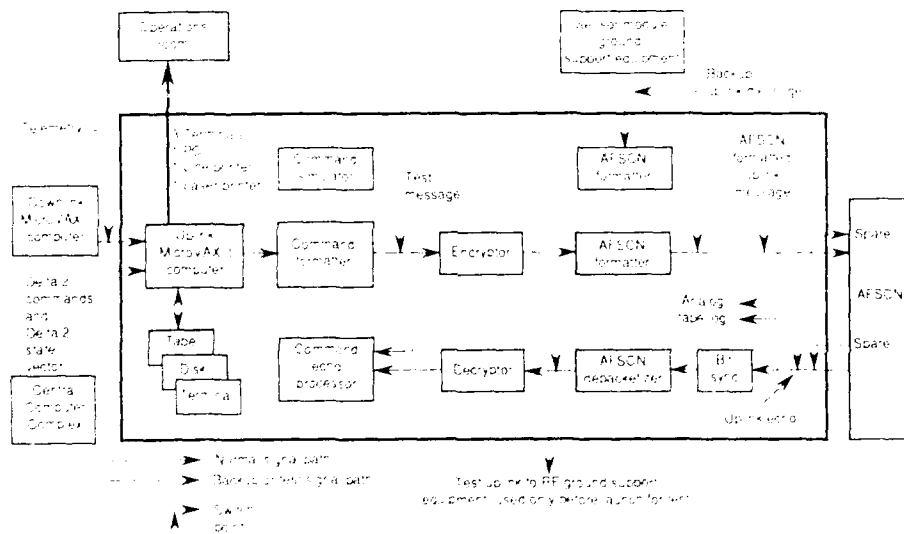


Fig. 3-1 Uplink subsystem block diagram.

3.1 COMMAND GENERATION

3.1.1 APLCOM Operation

Figure 3-2 shows a top-level data flow diagram of the uplink computer software. For clarity, only the basics are shown. Please refer to Fig. 3-2 as required in the following discussion. The APLCOM software program, resident in the uplink computer, provided the means to send and verify commands to the sensor module. The program, operated via the APLCOM terminal, was operator-interactive; various APLCOM language constructs allowed the operator to specify and send commands to the sensor module. The concepts behind APLCOM were developed at APL some time ago for similar applications. A unique version of APLCOM was designed for sensor module command and control.

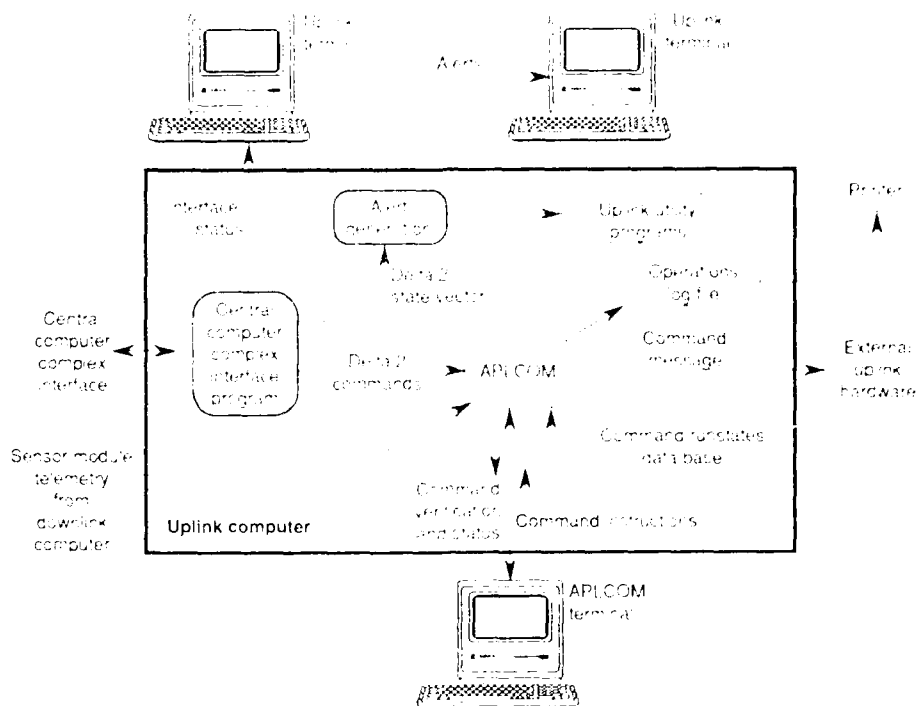


Fig. 3-2 Uplink software data flow diagram.

Commands were entered by the uplink controller and sent to the sensor module in the form of a command message. After entry of a command message (in API - COM language notation), APL.COM compiled a bit image of the message and passed it to the uplink hardware for transmittal to the sensor module. The command message bit image format is shown in Appendix C. As shown, a command message consisted of 2 to 100 commands imbedded in overlaying protocol. All command messages, including those destined for the Delta 2 guidance computer or the test objects, were packed in this format. The commands could be either real time (i.e., executed immediately when received by the sensor module), or delayed (i.e., stored in the sensor module command store memory for execution at a later time). The process of sending and verifying a single command message typically took 10 to 20 seconds, depending on message length and type.

3.1.2 Runstate Files

Closely associated with APL.COM operation was the use of command runstate files. A runstate was a text file of APL.COM language commands specifying one or more command message operations. APL.COM was designed to access a runstate file specified by the operator, and to execute commands in that file. A runstate basically substituted for operator type-in. The use of runstate files allowed for the configuration and test, prior to launch, of command messages intended for potential use during the mission. It also greatly minimized the potential for operator error. For this mission, about 50 such runstates were preconfigured, thoroughly tested, and placed in a runstate data base prior to launch. A number of these runstates were used during the mission.

3.2 COMMAND AUTHENTICATION AND VERIFICATION

In the design of a spacecraft command facility, the command verification process is always a prime concern. Because of the nature of RF uplinks, there is always a small probability that bit errors will occur in the uplink process. Reception by the spacecraft of bit errors in the command message will generally prevent the execution of one or more of the commands. Therefore, for reliable control of the spacecraft, the ground uplink design must include a means to verify command execution. For the Delta 181 mission, because of the extended ground network through which commands flowed, command verification and authentication (described below) were especially critical functions. These functions were performed automatically by APLCOM software; a brief overview is given below.

3.2.1 Authentication Word

In addition to command verification, the command center maintained and verified the command authentication word. (The sensor module command system required that each command message include the correct authentication word; see Appendix C.) The command authentication word, as well as encryption of the uplink, were features designed to enhance security of the command link. The authentication word was a "key" that allowed the command message to enter the sensor module command system—the message executed only if the sent authentication word matched the authentication word internally maintained by the sensor module.

After each command message was sent to and accepted by the sensor module, the authentication word internal to the sensor module changed. APLCOM automatically computed a new matching authentication word. The new authentication word, after verification in APLCOM, was saved for inclusion in the next command message. Computation of the new authentication word was based on the value of the authentication word just sent.

3.2.2 Authentication Word Verification

The change in sensor module authentication word status that occurred as each command message was accepted was immediately downlinked in telemetry. APLCOM monitored change in status and verified the new authentication word. The new authentication word, computed by APLCOM algorithm, was verified if it matched the authentication word imputed from telemetered status. If the new authentication word could not be verified, APLCOM reset the authentication word (to be packed in the next uplink command message) to its previous value. Failure to verify the authentication word indicated that the previous command message was not accepted and executed. In this case the normal procedure followed by the operator was to simply resend the previous message.

3.2.3 Verification of Command Execution

The new authentication word, when verified by APLCOM, indicated that the command message was received and command processing was initiated. To verify command execution by the sensor module command system, APLCOM compared replicas of the executed commands (which were returned in the narrowband telemetry) with commands sent in the previous command message. In the event the command message loaded delayed commands into the sensor module command store memory, the command message was authenticated and verified by APLCOM as previously described. In addition, APLCOM commanded the sensor module to telemeter the contents of stored command memory. The delayed commands stored in memory were then verified by comparison with an image of the sent commands.

APL COM completed the command authentication and verification process a few seconds following the transmission of each message. However, active telemetry input was required to do this. In normal command center operation, commands were not sent during a pass until telemetry input was first detected. To this end, the sensor module was programmed to turn on the narrowband telemetry automatically when it was over each telemetry site.

3.2.4 End-to-End Command Verification

The APL COM command authentication and verification processes described above verified execution of all commands through the sensor module command system. They indicated, with high probability, that the transmitted commands were executed by the respective sensor module subsystem, Delta 2 guidance computer, or test object. For complete end-to-end verification, telemetered status data from the respective subsystems were examined. For commands executed by sensor module subsystems, this was performed by the health evaluator and his team, located in the command center operations room. Monitoring the appropriate telemetry display pages, they verified that subsystem status was reflective of commands packed in the previous command message. Test object commands were verified in a similar manner in the Sandia National Laboratory facility. The Central Computer Complex facility, which configured the Delta 2 commands and accessed Delta 2 telemetry, performed end-to-end verification of Delta 2 guidance computer commands.

3.3 INTERFACE TO THE CENTRAL COMPUTER COMPLEX

3.3.1 Delta 2 Guidance Computer Command

For reasons previously noted, Delta 2 guidance computer commands could not be preconfigured and stored in the command runstates data base. These commands were configured in real time and sent to the command center from the Central Computer Complex. As shown in Fig. 3-2, the uplink computer included software to process input from the Central Computer Complex. When Delta 2 guidance computer commands were received, they were automatically input to APL COM. APL COM converted these commands into a sensor module command message and output the message for transmission to the sensor module. Operator interaction was required to send the message.

3.3.2 Delta 2 State Vector

The link to the Central Computer Complex also carried other useful information to the command center, which was processed by uplink computer software. Most notable of these data was the Delta 2 state vector periodically computed by the Central Computer Complex. The command center used the Delta 2 state vector to compute updated station alerts (i.e., the times at which each telemetry site was in view of the orbiting Delta 2 and sensor module). These were generated by an alerts program resident in the uplink computer. Alerts were required and used in overall operations planning. The latest alerts, accessed by the downlink computer display program, were placed on all telemetry data displays.

3.3.3 Health Message

Because of the nature of the mission, the reliability and availability of the interface link to the Central Computer Complex was a prime concern. If the opportunity to send Delta 2 guidance computer commands was lost due to link failure, these command operations generally could not be "made up" at the next available

pass. Thus, to enhance the reliability of this link, the Central Computer Complex transmitted health messages at 30-second intervals. The intent of the health message was to allow the uplink computer to detect link problems well before crucial Delta 2 uplink operations, so as to allow sufficient time for corrective action. To detect any link failure, uplink computer software continuously monitored the interface for any loss in health message activity. Loss of activity implied a link failure and resulted in appropriate operator notification.

3.3.4 Interface and Message Form

Data transmissions between the Central Computer Complex and command center were carried over a single RS-232 standard interface (9600-baud rate, asynchronous character, full duplex). Each message was sent in the form of an ASCII character text string and involved a "handshake" operation. The specification of all message types and interchange protocol is detailed in Ref. 2.

3.4 COMMAND UPLINK HARDWARE DESIGN FEATURES

To send a command message to the sensor module, the uplink computer packed the command message into an uplink image as described in Appendix C. However, command uplink hardware was required to transform the computer image to an electrical signal suitable for communication through the AFSCN. In addition, encryption of the command message was performed in the uplink hardware. This equipment was made up of the command formatter, the encryptor, and the AFSCN formatter (Fig. 3-1).

3.4.1 Command Formatter

To send an uplink message, the computer passed an image of the command message to the command formatter. After receipt and error check, the command formatter propagated the message, in the form of a 1 kb/s command bit sequence, into the encryptor. (Because of AFSCN transport timing requirements, the accuracy of the bit rate, set by the command formatter, had to be better than 0.02% of nominal.) For communication through the AFSCN, the encrypted message was packed into contiguous AFSCN 48-bit frames by the AFSCN formatter. See Appendix D for a description of the AFSCN format and additional AFSCN interface detail.

3.4.2 Idle Null Messages

The AFSCN formatter, in addition to formatting the encrypted uplink message, generated and transmitted "idle null" messages between propagation of uplink messages. As will be discussed in the following section on verification of the ground uplink, this allowed command center operators to easily determine the functional state of the entire ground portion of the uplink at any time.

The "idle null" messages, continuously output by the command center between command messages, also allowed AFSCN equipment to maintain continuous synchronization to the 48-bit AFSCN frames (during each pass). This allowed the AFSCN to be configured such that no action by AFSCN operators was required to send or verify individual command messages. The command center output directly controlled the RF uplink modulation at the active uplink station. As described in Appendix D, "idle null" messages resulted in an RF carrier with no uplink command modulation. When encrypted command messages were sent, they resulted in "1" and "0" tone modulation of the carrier; this modulation reflected the bit

sequence seen at the command center encryptor output. Total transport delay through the AFSCN (i.e., the delay between a bit occurring at the command center encryptor output and the resulting modulation on the RF uplink) was between 1.7 and 1.8 seconds.

3.4.3 Redundancy

For redundancy, a dual set of cable links carried the command message from the command center to the AFSCN Eastern Vehicle Checkout Facility at Cape Canaveral. Both cable links were active at all times. Normally the AFSCN facility selected the primary line for uplink through the AFSCN. In the event of primary cable link failure, it could switch over to the backup uplink cable.

3.5 VERIFICATION OF THE GROUND UPLINK

The uplink subsystem included the capability to verify functionality of the entire portion of the ground uplink, including the AFSCN assets. This was a key feature of command center design. Typically, during each revolution of the in-orbit sensor module, command uplinking was performed from more than one uplink site. The uplink thus was reestablished and verified a number of times during each orbital period. A means to quickly determine the functional status of the link before each pass, and take corrective action if necessary, was vital to maintaining reliability and availability of the command link. The following paragraphs describe the design of the command center's capability to verify the entire ground uplink.

3.5.1 Command Echo

In order to perform verification of the ground uplink, the AFSCN was configured to return to the command center a real-time image of AFSCN command input. This signal, called the command echo, was derived during supported uplink passes by detection of RF carrier modulation at the uplink site. The command echos were received in the identical format as output to the AFSCN, i.e., packed in AFSCN 48 bit frames. The return echo was continuous and included the "idle null" messages inserted between command messages. The command center included equipment (Fig. 3-1) to process the command echo, and to verify functionality of the ground uplink.

3.5.2 Echo Processing

3.5.2.1 Level 1. The command center performed echo processing at two different levels. The first level, referred to as level 1, involved only the bit sync and AFSCN depacketizer shown in Fig. 3-1. A level 1 check was a simple yet powerful test that could be performed at any time. It required only that the command center be powered and that an echo loopback be connected at some point in the AFSCN. When powered, the command center continuously sent "idle null" messages to the AFSCN, as previously described. The command echo then consisted of a stream of "idle null" messages. The depacketizer, which performed the inverse function of the AFSCN formatter, continuously monitored the return command echo for frame synchronization, parity, and message content. If AFSCN frame and parity was continuously maintained, this indicated (with a high probability) that the link was functional through the loopback point. Indicators on the depacketizer front panel gave operators a continuous reading of uplink status. This test was very useful, as it enabled the uplink to be easily checked at any time.

3.5.2.2 Level 2. The command center echo processing equipment also performed a level 2 test that involved a direct check of uplink command messages. This involved the decryptor and echo processor equipment shown in Fig. 3-1. When uplink messages were sent, the return command echo, after depacketization, was decrypted and compared in the echo processor with the transmitted command message. The echo processor also verified that these command messages were packed in the correct sensor module format. Level 2 testing was used to directly examine, at the command center, each uplink message radiated from the uplink sites.

3.5.3 Echo Utilization

The command echo, from an operational perspective, was used as follows. Prior to each pass, the AFSCN reconfigured to establish a command link to the appropriate uplink site. Generally, about 20 minutes before the pass, the link was established and the command echo was looped back from that site. Command center operators, employing both level 1 and level 2 checks, verified that the command link was ready to support the pass. In the event a problem was detected, command echo processing then served as a rapid ground fault isolation tool. By successively looping back from points within the AFSCN and command center, the faulty facility or equipment was readily determined. Figure 3-3 shows typical loopback points within the AFSCN and command center.

3.5.4 Echo Monitoring

During the pass, command center operators continued to monitor the command echo. It should be stressed, however, that the RF uplink transmission of each command message was not contingent on ground uplink verification. Commands were sent and verified by APLCOM program software as previously described. The command echoes were monitored so that, in the event of failure to command, it could be quickly determined whether the fault was in the ground uplink or the sensor module. In general, for pre-launch test operations and post-launch mission operations, command center ground uplink test capabilities provided great insight into AFSCN performance.

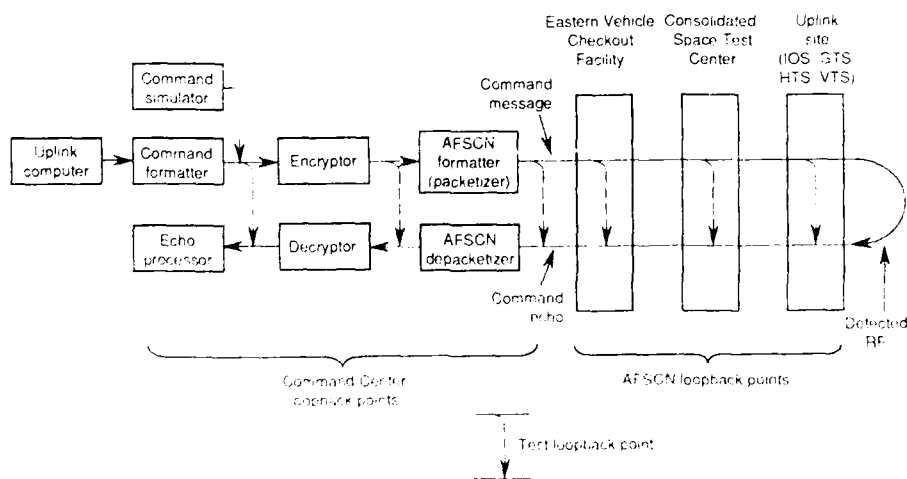


Fig. 3-3 Major loopback points for ground uplink test.

4. DOWNLINK SUBSYSTEM DESIGN

The basic function of the downlink subsystem was to enable the command center operating staff to monitor sensor module health and performance during the data-collection phase of the mission. To this end, the following "classic" telemetry capabilities (usually found to some degree in any spacecraft command and control center) were provided:

1. Real-time (i.e., during a pass) formatted display and printout of all sensor module narrowband telemetry data.
2. Real-time limits test of selected sensor module narrowband telemetry data.
3. Log of real-time narrowband telemetry data.
4. Access to logged pass telemetry data for display, printing, and testing.

A more detailed hardware breakdown of the command center downlink is shown in Fig. 4-1. A detailed description follows.

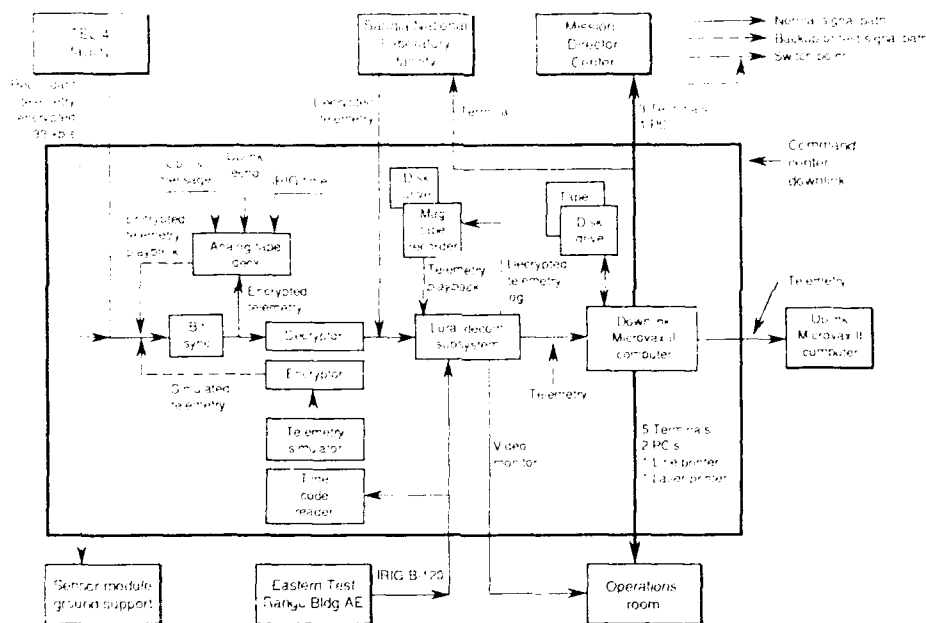


Fig. 4-1 Downlink subsystem block diagram.

4.1 DISPLAY COMPUTER

The primary equipment for providing formatted display and printing capability was the downlink MicroVax II computer (Fig. 4-1). That computer provided telemetry display to the command center operations room, the Mission Director Center, and the Sandia National Laboratory facility. The computer also supported printers located in the operations room. A menu-driven display program installed on the computer allowed the operator at each terminal to select from a list of preconfigured display pages. Each page, in addition to displaying up to 30 telemetered parameters, included station alerts information. From each terminal, the operator could select a data page printout at any time.

The downlink computer also was connected to personal computers in the command center operations room and in the Mission Director Center. These downlink personal computers were used mainly to provide specialized tabular and graphic displays of sensor module flight processor data following selected passes (e.g., a "map" of test object location and velocity). During each pass the computer stored all real-time flight processor data to a disk file; following the pass, the stored flight processor data could be accessed by the personal computers.

The downlink computer also provided an output of decommutated telemetry and time tags to the uplink MicroVax computer over an Ethernet link. This telemetry was required by the uplink computer to perform sensor module command and memory verification. The time tags were used to set the uplink computer clock.

4.2 TELEMETRY INPUT, DECRYPTION, AND DECOMMUTATION

The TEL-4 facility provided redundant real-time sensor module telemetry input to the downlink subsystem. The redundant inputs, each consisting of serial 33-kb encrypted data, were concurrently active whenever telemetry data were available. The command center downlink could be configured to use either input.

4.2.1 Telemetry Processing

Figure 4-1 shows the downlink equipment that processed and interfaced telemetry data to the downlink computer. Telemetry processing consisted of bit synchronization, decryption, and decommutation. Bit synchronization, performed by a DSI model 7700, was required to extract data and clock information from the TEL-4 input signal. The bit synchronized data were decrypted and input to a Loral model ADS-100 decommutator subsystem. The decommutator synchronized to the telemetry frame and provided decommutated data to the downlink computer. The basic decryption unit was a KGX-28 keyed to the sensor module telemetry encryption.

4.2.2 Other Decommulator Functions

The decommutator performed a number of functions in addition to decommutation and interface to the downlink computer. It provided additional formatted data displays and printout capability, data limits checking, and a decrypted data log. A video monitor unit located in the operations room presented decommutator generated data display pages. The decommutator time-tagged each received telemetry frame, and logged each telemetry data frame and respective time tag to a digital tape recorder. Logged data could be played back and processed in the downlink computer in the same manner as real-time data.

The data limit feature of the decommutator allowed the operator to specify high and low alarm limits to selected telemetry data parameters. When this test feature was enabled, received data that exceeded the specified limits would cause a visual and audible alarm message to be posted. This feature allowed quick and automated checks of sensor module health and status during selected passes during the mission.

The command center received IRIG-120-B time standard input from the Eastern Test Range. This time information was input to the Loral decommutator subsystem to set clocks both in the Loral Decommulator and MicroVax computers.

4.2.3 Encryption/Decryption Pairs

Please note that, for security reasons, it was required to "hand" encryption hardware in its mounting racks. Also, these decryption units did not have any status

indicators. Thus detection and repair of a failed decryptor unit would normally be a time-consuming operation. To remain operational in the event of a failure, the downlink decryption/encryption chassis design included two decryption units and two encryption units. The second decryption unit provided a hot spare in the event the first decryptor failed. If it was determined a decryptor failed, the alternate decryptor could be switched in by simply toggling a switch. The encryptors were included for rapid test and fault isolation of the decryptors. Comparison of the input and output of an encryption/decryption pair, connected in series for test, provided a quick and convenient means to ascertain decryptor functionality.

4.3 DATA LOG CAPABILITIES

In addition to the digital tape recorder used to record decrypted, time-tagged telemetry, the downlink also included a Honeywell analog tape recorder. This recorder logged encrypted TEI-4 input. In addition, the analog recorder logged time, encrypted uplink command messages, and the return command echo.

Both tape recorders were used for operations and data logging during the mission. Also, prior to launch, they were heavily used for command center test and fault isolation. While the command center was integrated and tested at APL, a number of tape recordings were made of actual sensor module narrowband telemetry. After installation at Cape Canaveral, and prior to a number of critical control complex integration tests, playback of encrypted telemetry proved especially useful for verifying command center functionality.

ACKNOWLEDGMENTS

The Delta 181 sensor module command center was designed, installed, and integrated at CC AFS in a short time frame (about one year). Success in design and operation was achieved only because of great effort on the part of many people at both APL and other participating organizations.

BIBLIOGRAPHY OF DELTA 181 PROGRAM DOCUMENTS

The following documents specify the Delta 181 mission and program requirements in detail:

1. *Delta 181 Mission Timeline Phase 1 - Data Collection for Sensors, VCR and RF Downlink Operations*, JHU/APL S2C-SSR 005 (Jan 1988).
2. *Delta 181 to ETR Interface Specification*, McDonnell Douglas Astronautics Company (Dec 1987).
3. *Annex A, Delta 181 Orbital Requirements*, McDonnell Douglas Astronautics Company PRD OR RD 2515 (Dec 1987).
4. *Instrumentation Developed by The Johns Hopkins University Applied Physics Laboratory for Non-APL Spacecraft*, JHU/APL SDO-4100 (Sep 1988).
5. *Delta 181 Mission Performance Quicklook Report*, JHU/APL SDO-8676 (Mar 1988).

APPENDIX A— SENSOR MODULE COMMAND AND TELEMETRY LINKS

COMMAND UPLINK

As shown in Fig. A-1, the sensor module RF uplink carried commands executed in the sensor module. However, this link was unique in that it also carried commands destined for the Delta 2 inertial guidance computer (built by MacDonnell Douglas) and to four test objects built by the Sandia National Laboratory. The sensor module served as a conduit for inertial guidance computer and test object commands. Commands received by the sensor module were interpreted in the command system and, depending on type, were either (1) executed within the sensor module, (2) relayed to the Delta 2, or (3) transmitted to the respective test object.

The sensor module uplink (in terms of frequency selection, modulation structure, bit encoding, etc.) was SCGSS compatible. (SCGSS is an Air Force abbreviation for Space Ground Link Subsystem.) The four Air Force Satellite Control Network tracking sites used for uplink were already SCGSS-compatible and thus required only minor upgrades to support the mission.

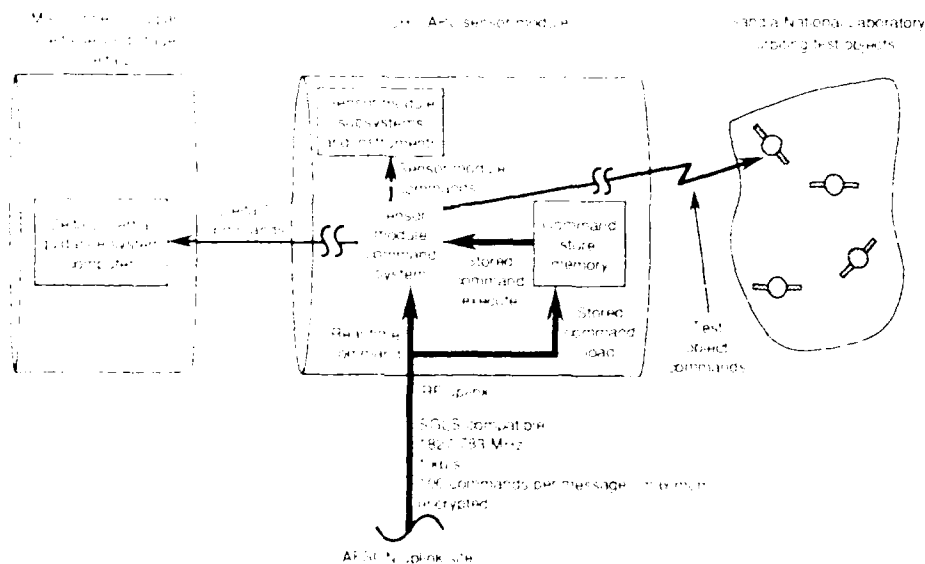


Fig. A-1 Uplink command flow for orbiting sensor module, Delta 2, and test objects.

The command structure as shown minimized the overall need for command system flight hardware and ground uplinks. However, this approach did place additional burdens on command center design and operation. First, the command center had to send commands to the inertial guidance computer and test objects (in addition to the sensor module). In addition, the command verification process for these additional commands was somewhat more complicated than verification of sensor module commands. Sensor module commands, sent by the command center and executed by the sensor module, were verified completely within the command center. Thus, from an operational perspective, this was a relatively straightforward

process. However, the command center could verify Delta 2 commands and test object commands to only a limited degree. Complete end-to-end verification of those commands required support from facilities and expertise outside the command center. Operationally, sending and verifying the execution of these commands required a very high degree of coordination between the command center and other control complex facilities.

TELEMETRY DOWNLINKS

The orbiting sensor module and Delta 2 telemetry downlinks are illustrated in Fig. A 2. The sensor module had three telemetry links, a narrowband (33 kb/s) link and two wideband (1 Mb/s) links. The narrowband link carried sensor module data required by the command center to perform real time command and monitor operations. It was received by control complex tracking sites and sent in real time to the command center. Narrowband telemetry was a composite of sensor module housekeeping data (e.g., temperatures, voltage, and current measurements, and sensor module instrument status), sensor module flight processor data, and Sandia National Laboratory test object telemetry. A major component of flight processor data was position and velocity information maintained by the flight processor on a number of test objects.

The two wideband telemetry links carried science data generated by the sensor instruments. During the data-collection phase of the mission, the wideband data, downlinked over select spacecraft tracking sites, was derived in real time from the sensor instruments. Note, however, that the bulk of science data generated during the data-collection phase was stored on tape recorders and retrieved on the ground at a later time. During the data-retrieval phase of the mission, wideband data consisted of science data played back from the on-board recorders. Data from these links were recorded at 13 tracking sites and processed following the mission. Wideband data were not required by the command center for real-time command and control operations.

The sensor module downlinks (in terms of frequency selection, modulation structure, bit encoding, etc.) were also SGIS-compatible. All 13 tracking sites in the control complex were SGIS-downlink compatible, and thus were capable of receiving and processing sensor module telemetry.

The Delta 2 vehicle had three telemetry downlinks. Data telemetered in these links were received at selected control complex tracking sites and sent in real time to facilities located at Cape Canaveral Air Force Station. These links were not input to the command center; they were processed by MacDonnell Douglas installations outside the command center. Of special note, however, was the inclusion of inertial guidance computer data in Delta 2 telemetry. Real-time inertial guidance computer data, telemetered to the control complex, was used to verify end-to-end Delta 2 inertial guidance computer commands previously sent from the command center.

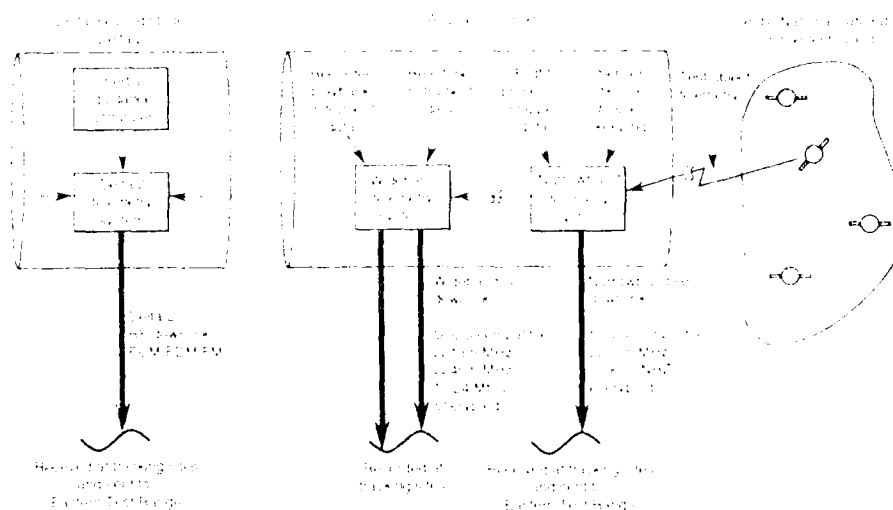


Fig. A-2 Orbiting sensor module, test objects, and Delta 2 telemetry links.

APPENDIX B— TELEMETRY AND UPLINK STATION CONTACTS

Table B-1 lists control complex telemetry and uplink contacts with the sensor module during the data-collection phase. At every available opportunity, when a telemetry site was in view of the sensor module, narrowband telemetry was returned to the command center. Telemetry data were displayed in order to monitor sensor module health and status; the deployment and tracking of test objects were also monitored at key points during the mission. The command center experienced multiple contacts during each orbit of the sensor module, as a result, command center operations during this phase were continuous and intense.

The command center, for some orbits, sent command messages from a number of uplink sites. The AFSCN and command center had to rapidly reconfigure and test the command uplink before each of these passes. The ability of the command center to rapidly verify the ground uplink, as described in the main text of this report, played an important role in the overall success of command operations.

The uplink command messages, as a function of orbit and uplink site, are given in Ref. 5. Generally, two types of commands were sent, Delta 2 inertial guidance computer commands and sensor module flight processor commands. As described in the main text, the Delta 2 commands were configured in the central computer complex and sent to the command center. The sensor module flight processor commands, configured and sent by the command center, enabled or disabled flight pro-

cessor functions. These commands were sent in response to contingencies that occurred during the mission. Command runstates for these contingencies were configured before launch. Also note, at the GTS (Guam) site on the ninth orbit, the command center uplinked a new load to the sensor module commands store memory. This load provided delayed command instructions to the sensor module for data retrieval operations. Beginning on the tenth orbit, the AFSCN began retrieval of data played back from on-board recorders.

Wideband telemetry contacts with control complex sites is also shown. Note, however, that this data was not sent to the command center; it was logged on tape at these sites and processed following the mission.

Table B-1
Delta 181 telemetry and uplink site sensor module
contacts for the data-collection phase.

Orbit	Site	NB	WB	Uplink
2	USAKA	x	x	
2	HAW	x	x	
2	HTS	x		x
2	VTG	x	x	x
2	MILA	x	x	
2	JDIF	x	x	
2	ANT	x	x	
2	ASC	x	x	
3	GTS	x	x	x
3	USAKA	x	x	
3	HAW	x	x	
3	HTS	x		x
3	VTG	x	x	x
3	MILA	x	x	
3	JDIF	x	x	
3	ANT	x	x	
3	ASC	x	x	
4	GTS	x	x	x
4	HAW	x	x	
4	HTS	x		x
4	VTG	x	x	x
5	GTS	x	x	x
5	HAW	x	x	
5	HTS	x		x
5	IOS	x	x	x
6	HAW	x	x	
6	HTS	x		
6	IOS	x	x	x

Table B-1

Delta 181 telemetry and uplink site sensor module
contacts for the data-collection phase. (cont'd)

7	HAW	x	x	
7	HTS	x		x
7	ASC	x		
8	GTS	x		x
8	USAKA	x		
8	ASC	x		
9	GTS	x		x
9	USAKA	x		
9	ASC	x		

AFSCN begins data retrieval

10	GTS	x	x	x
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Notes: NB = narrowband telemetry contact
WB = wideband telemetry contact
Uplink = command uplink contact

Uplink and telemetry sites:

Air Force Satellite Control Network (AFSCN)

IOS - Indian Ocean Station
GTS - Guam Tracking Site
HTS - Hawaii Tracking Site
VTS - Vandenburg Tracking Site

Goddard STDN Sites

MILA - Merritt Island Launch Area
GWM - Guam
HAW - Hawaii
ACN - Ascension Island

Eastern and Western Test Range Sites

IDIF - Johnathon Dickerson Instrumentation
Facility
ANT - Antigua Island
ASC - Ascension Island
VTRS - Vandenburg Tracking Site
USAKA - U.S. Army Kwajalein Atoll

APPENDIX C— SENSOR MODULE COMMAND MESSAGE FORMAT

Commands were packed and sent to the sensor module in the form of a command message. Each message was a bit sequence organized and formatted as shown in Fig. C-1. The bit sequence was encrypted and modulated onto the RF uplink carrier at 1 kb/s. A decryptor on board the sensor module recovered the plain text message. The command message format is an artifact of the sensor module command system; therefore sensor module, Delta 2 inertial guidance computer, and test object commands were all packed and encrypted in this same format.

As shown, each command message included a preamble, an authentication word, a sync word, a commands field, and a postamble. The commands field was variable in length and contained up to 100 commands. Each command mapped into a 64 bit sub-field. The commands field was always terminated with an end-of-message command; thus, the shortest command message always included at least two commands. The commands could be either real-time (i.e., executed immediately when received by the sensor module), or delayed (i.e., stored in the sensor module commands store memory for execution at a later time). However, a particular command message could consist of only one type.

At the appropriate AFSCN uplink site, the command message was modulated (SGLS format) onto the RF uplink carrier. The shortest command message took approximately 0.6 second to transmit. The longest message (100 commands) took about 7 seconds. The transmission of each message required only "1" and "0" bit modulation (no "set" bits) on the uplink carrier.

An important aspect of each command message was the inclusion of a 32-bit authentication word. The sensor module would accept the message and initiate command execution only if the transmitted authentication word matched the authentication word maintained in the sensor module command system. When the sensor module accepted the transmitted authentication word, it processed the command message and updated its internal authentication word. The value of the updated authentication word was based on the previous authentication word value. The next command message sent, in order to be received and processed, had to include the updated authentication word.

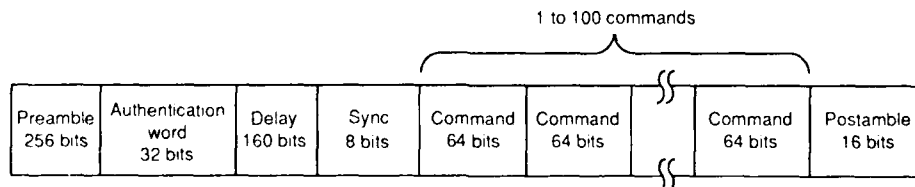


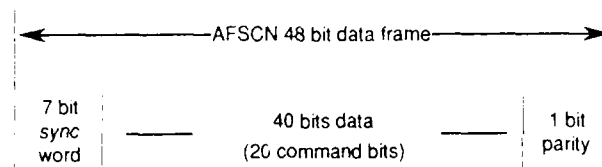
Fig. C-1 Uplink command message format.

APPENDIX D— FORMAT OF COMMAND CENTER OUTPUT TO THE AFSCN

Command messages generated by the sensor module command center were sent to the orbiting sensor module via the AFSCN. This required that command messages sent from the command center be packed in the AFSCN 48 bit frame format as defined in Fig. D-1. In the command center, a component called the AFSCN formatter packed the command message into the AFSCN format for transmission through the AFSCN. At the remote uplink site, the inverse formatting process was performed, i.e., the command bits were "unpacked" from the 48 bit frames to modulate the uplink carrier at 1 kb/s.

As shown in Fig. D-1, each 20 bit segment of the command message (command bits) were converted to a 48 bit AFSCN frame consisting of 7 sync bits, a 40 bit data field, and a parity bit. The 40 bit data field resulted from a di-bit conversion of the 20 command bits. The conversion process was in real-time and continuous and the AFSCN formatter output data rate was exactly 48/20 times the 1 kb/s command bit rate.

The command center AFSCN formatter, between uplink messages, provided an output of idle null messages (Fig. D-2). For the idle null message, the data field



1 command bit = 2 frame bits

Sync word	Command data bits	Frame bits	Parity
1110010	1	10	Indicates bit parity
	0	01	within command bit
	null	00	segment of frame.
	set	11	Even parity.

$$\text{Ratio: } \frac{\text{Command data bits}}{\text{Frame bits}} = \frac{20}{48} = \frac{1 \text{ kb/s}}{2.4 \text{ kb/s}} \quad \text{Frequency accurate to } \pm 0.021\%$$

Fig. D-1 AFSCN 48 bit frame format.

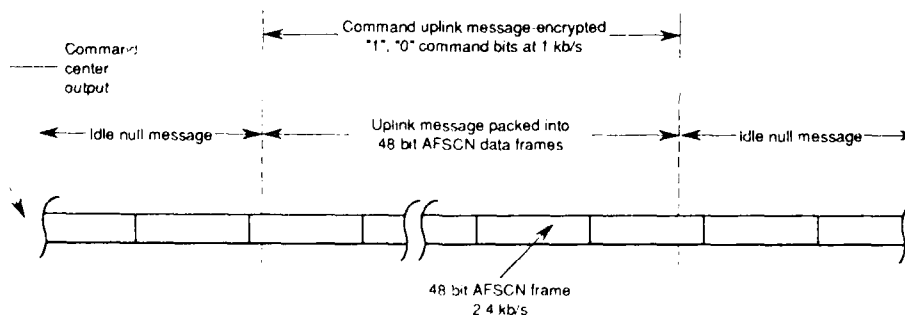


Fig. D-2 Command center output to the AFSCN.

of the 48 bit field consisted of di-bit-converted "null" bits. Transitions between the idle null message and the encrypted uplink message was accomplished such that clock and frame synchronization was maintained. This allowed AFSCN equipment to maintain continuous synchronization and error check of the command center output throughout each pass, irrespective of the data content of the 48 bit frames.

AFSCN equipment was configured such that command operation was automatic; i.e., no AFSCN operator interaction was required to send individual command messages. The idle null messages resulted in no uplink modulation of the RF carrier (the RF carrier was on continuously throughout each pass). Uplink messages were automatically detected by AFSCN equipment and resulted in command message modulation of the carrier.

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